On Forward Jets and the Hot Spot Limit at HERA

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Abstract: A Monte Carlo study of forward jets in deep inelastic lepton–proton scattering at HERA is presented. The jets are identified with an extension of the JADE algorithm which differs from the JADE algorithm by jet mass terms.

A new variable for the transverse hadronic activity, $\kappa^2 = E(E - P_Z)$, is introduced and investigated in the "Hot Spot Limit", i.e. at high jet energies, high transverse jet momenta and low Bjorken–x (x_{Bj}). It is shown that a study of the shape of the κ–distribution allows to discriminate between the predictions of two Monte Carlo programs, which are based on a color dipol model and a parton shower model, respectively.

1 Introduction

Transverse energy flow measurements of H1 and ZEUS at small x_{Bj} seem to indicate that the DGLAP evolution of the parton densities [3] is underestimating the data [4]. It is expected that the BFKL evolution [8] which is applicable in the small Bjorken–x (x_{Bj}) region, is producing more transverse hadronic activity than the DGLAP evolution. However the transverse energy flow is not an infrared–safe observable, and it may turn out that the observed gap between the DGLAP evolution and the data is mostly due to hadronization effects, so that non–perturbative models, such as the Soft Color Interaction model [2], are able to explain the gap [12].

Jets of high energy and high transverse momentum, i.e. hard jets, at very low x_{Bj} are expected to be suited for a search for new QCD phenomena, such as Hot Spots [11]. Hot Spots are small regions in the proton where the parton densities are so large that parton recombination processes are more dominant than parton splitting processes, which are the dominating processes at high x_{Bj}. Experimental evidence for new QCD phenomena can be found by looking for discrepancies between the data and predictions of conventional theoretical approaches. Hot Spots, for example, are believed to suppress differential jet cross sections compared to standard approaches because of recombination processes of partons in the proton [11]. In Ref. [4] first measurements of the cross section of hard jets at low x_{Bj} were presented. The results seem to favour the BFKL evolution over the DGLAP evolution, however a firm conclusion could not be extracted from the data. Cross sections are difficult to measure. In this study we are looking for a different signature of new perturbative QCD phenomena. The idea is to take into account that the recombination processes could influence the hadronization of partons in such way that on the hadron level certain distributions of hard jets differ not only in the normalization but also in the shape from predictions of conventional Monte Carlo programs. Shapes are easier to measure than cross sections, i.e. a different possibility to find evidence for new QCD phenomena would be to find a jet variable which shows, for hard jets, significant discrepancies in the shape between the data and conventional Monte Carlo programs.

As a first step we identify in this work a jet variable which discriminates between two different Monte Carlo models: a MEPS model which is based on low order QCD matrix elements and parton showers [6], and a color dipol model (CDM) [9].

2 Extended JADE Algorithm

In Ref. [5] a jet clustering algorithm was deduced from a few conditions of general nature, such as energy–momentum conservation, Lorentz invariance and infrared safety[1]. The jet clustering is applied to a set of momenta $p_1, \ldots p_N$. First, the squared distance $d_{ij}^2 = (p_i+p_j)^2-(m_i+m_j)^2$is assigned to all pairs of momenta p_i and p_j, where $i < j \leq N$ and $m_i = \sqrt{p_i^2}$ is the mass of the i–th momentum. Secondly, the momenta p_i and p_j are recombined to the momentum $p_i + p_j$ (E–scheme), if d_{ij} is not only the smallest of all distances but also smaller than a reference distance $\sqrt{y_{\rm cut}} M_{\rm ref}$, where $M_{\rm ref}^2 = (p_1+p_2+\ldots)^2 - (m_1+m_2+\ldots)^2$. $y_{\rm cut}$ is called jet resolution parameter and $M_{\rm ref}$ reference mass. The second step is iterated until all distances are larger than the reference distance. The final set of momenta defines the jets of the hadronic final state.

The proton remnant is identified as the jet with the smallest distance $d_{i\,{\rm prot}}$ to the momentum of the incoming proton. Within the set of the non–remnant jets, the jet with the smallest distance $d_{i\,{\rm prot}}$ to the incoming proton momentum is called the forward jet. We stress that this interpretation of the forward jet will be applied to each event, also to (1+1) jet events, despite the fact that because of kinematic constraints the current jet of (1+1) jet events may not be emitted into the region around the proton direction in the HERA laboratory frame.

The jet resolution parameter is set in the following to $y_{\rm cut} = 0.02$.[2]

3 Hot Spot Limit

Heisenberg's uncertainty relations suggest that subregions in the proton may be investigated, if the energy of forward jets with a high transverse momentum is increased.

The basic idea of the following analysis is to find a jet variable whose distribution has a shape which is not identical for the conventional Monte Carlo programs DJANGO6–MEPS[3] and DJANGO6–CDM[4], respectively, if the behavior of high transverse momentum jets ($p_T^2 \sim Q^2$) is studied in the limit of high energies and small $x_{\rm Bj}$

$$\xi = \frac{x_{\rm Bj}}{E_{jet1}/E_{\rm prot}} \to 0, \tag{1}$$

where E_{jet1} is the energy of the forward jet. A study of this kind was suggested in the context of Hot Spots [11]. Therefore, the limit (1) will be called Hot Spot Limit in the following.

[1] A jet algorithm is infrared safe if it does not resolve infrared or collinear momenta.

[2] For the extended JADE algorithm it can be shown that at $y_{\rm cut} = 0.01$ and at high Q^2 (> 100 GeV^2) the next–to–leading order correction factors (K–factors) to the (2+1) jet cross sections in leading order are reasonably small ($K \sim 1.3$).

[3] DJANGO6–MEPS [1] is an interface between the Monte Carlo programs LEPTO [6] and HERACLES [13].

[4] DJANGO6–CDM [1] is an interface between the Monte Carlo programs ARIADNE [9] and HERACLES.

Jets in the Hot Spot Limit should be sensitive to perturbative (multi–parton) effects and only weakly influenced by non–perturbative hadronization effects since, on the one hand, in the Hot Spot Limit subregions in the proton should be probed and since, on the other hand, hadronization effects are long distance effects.

It is a non–trivial task to find a jet variable which is shape sensitive in the Hot Spot Limit, mainly because there is no information from theory available, as to how a shape sensitive jet observable should look like. For example, it turns out that the shape of the transverse momentum distributions of the forward jet does not change very much in the Hot Spot Limit.

Let us introduce the observable $\kappa^2 = E(E - P_Z)$, i.e. the energy weighted $E - P_Z$ of the forward jet. The qualitative agreement in the shape of the κ distribution between the Monte Carlo predictions is lost if $x_{\rm Bj}$ is decreased and the energy of the forward jet is increased at the same time (see Fig. 2, where the κ distribution is shown for the jet energies larger than $10, 15$ and 20 GeV).

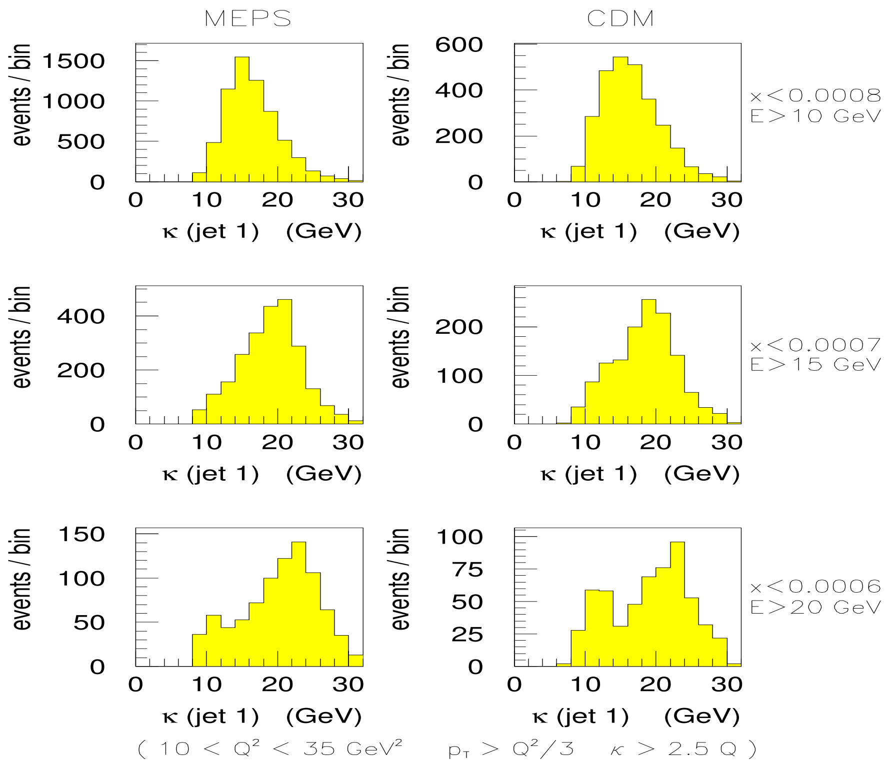

Figure 1: *Comparison of the Hot Spot Limit of the κ distribution on the ZEUS detector level using the Monte Carlo programs DJANGO6–MEPS and DJANGO6–CDM. (The kinematic range is limited to $13\,\mathrm{GeV}^2 < Q^2 < 35\,\mathrm{GeV}^2$. Moreover, it is required that the forward jet has a high transverse momentum, $p_T^2 > Q^2/3$, and a high "energy weighted $E - P_Z$", $\kappa > 2.5\,Q$. The distributions of the partons inside the proton are taken from the MRSD–' set [10].)*

It can be shown that the discrepancies with respect to the peak structure are stable against the experimental uncertainties in the hadronic energy scale, one of the most important experimental uncertainty. The contribution to the systematic error from the uncertainty in the leptonic energy scale is small. Moreover, it turns out that there is a (weak) correlation between the generated and reconstructed events, indicating that the influence of the ZEUS detector on the κ distribution in the Hot Spot Limit can be unfolded. Thus, the ZEUS detector seems to be suitable to measure the κ distribution in the Hot Spot Limit.

Newer versions of ARIADNE and LEPTO were published, now with similar predictions for the forward energy flow. It can be shown, however, that the discrepancies found here are still present.

In summary, a measurement of the shape of the κ distribution of the forward jet in the Hot Spot Limit may lead to an improvement of the understanding of perturbative QCD.

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References

[1] K. Charchuła, G. A. Schuler and H. Spiesberger, *DJANGO6*, version 1.1, Comp. Phys. Commun., **81** (1994) 381.

[2] A. Edin, G. Ingelman and J. Rathsman, Phys. Lett. **B 366** (1996) 371.

[3] V. N. Gribov and L. N. Lipatov, Sov. Journ. Nucl. Phys. **15** (1972) 438 and 675;
Y. L. Dokshitzer, Sov. Phys. JETP **46** (1975) 641;
G. Altarelli and G. Parisi, Nucl. Phys. **B 126** (1977) 297.

[4] H1 Collab., Phys. Lett. **B 356** (1995) 118;
ZEUS Collab., Phys. Lett. **B 338** (1994) 483.

[5] H. Heßling, DESY 95–069.

[6] G. Ingelman, *LEPTO*, version 6.1, Proceedings 'Physics at HERA', W. Buchmüller, G. Ingelman (eds.), DESY Hamburg 1992, vol. 3.

[7] G. Kramer, DESY 82–029 (1982), published in Proc. of the 13th Spring Symp. on High Energy Physics, Bad Schwandau/GDR (1982);
JADE Collab., W. Bartel et al., Phys. Lett. **B 119** (1982) 239;
JADE Collab., W. Bartel et al., Z. Phys. **C 33** (1986) 22;
JADE Collab., S. Bethke et al., Phys. Lett. **B 213** (1988) 235.

[8] L. N. Lipatov, Sov. J. Nucl. Phys. **23** (1976) 338;
E.A. Kuraev, L. N. Lipatov, V. S. Fadin, Sov. Phys. JETP **45** (1977) 199;
Y. Y. Balitskii, L. N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822.

[9] L. Lönnblad, *ARIADNE*, version 4, Comput. Phys. Commun. 71 (1992) 15.

[10] A. D. Martin, W. J. Stirling and R. G. Roberts, Phys. Lett. B306 (1993) 145.

[11] A. H. Mueller and H. Navelet, Nucl. Phys. **B 282** (1987) 727;
A. H. Mueller, Nucl. Phys. B (Proc. Suppl.) **18 C** (1991) 125.

[12] N. Pavel, Workshop "DIS 96", Rome 1996.

[13] H. Spiesberger, *HERACLES*, version 4.4, unpublished program manual (1993); version 4.0 is described in A. Kwiatkowski, H.–J. Möhring and H. Spiesberger, Comp. Phys. Commun. **69** (1992) 155.